Abstract

Time series analysis and spectral analysis of data have important applications in most areas of science and engineering They have become even more critical in the present day when mountains of data are generated and sophisticated techniques are essential to discern underlying patterns and causal relations One prime example of this is in the area of neuroscience where recent advances in technology generate multi-channel signals over multiple trials Such data is best modeled using stochastic processes like multivariate autoregressive models In this thesis, we study three problems related to time series analysis of neurobiological signals

The power spectrum of most signals encountered in neuroscience change with time as the signals are non-stationary On the other hand, the standard spectral analysis techniques are valid only for stationary processes To get around this problem, we must analyze the signals using short-time windows of 50-100ms duration In this thesis, we compare two modern methods for estimating the power spectrum for short time series, namely adaptive multi variate autoregressive (AMVAR) and multitaper methods By analyzing a simulated signal (embedded in a background Ornstein Uhlenbeck noise process), we demonstrate that the AMVAR method performs better at detecting short bursts of oscillations when compared to the multitaper methods We also demonstrate that AMVAR method can detect peaks in the coherence spectrum of a noisy bivariate time series even though the corresponding peaks in the individual power spectra are undetectable due to noise

Having determined that AMVAR method is suitable for analysis of short data, we then apply it to data from a neuroscience experiment By performing short window spectral analysis on local field potential (LFP) data from the motor cortex of macaque monkeys performing a visual discrimination task, we find that AMVAR method is able to reliably detect the duration of beta oscillations

The second part of the thesis deals with prediction of hand movement direction prior to the start of the actual movement This study is part of a larger area of research on brain machine interfaces This research has potential applications in developing neural prosthesis for the benefit of amputees and paralyzed patients In this thesis, we consider an experiment where a macaque monkey moves its hand in one of the eight directions based on visual cues. The goal is to predict the direction of movement correctly before the hand movement actually starts The signals are recorded from an array of microelectrodes implanted in the monkey's motor cortex. The problem now reduces to using a single trial multichannel data and classifying it in the appropriate direction of hand movement By computing the power in the gamma frequency band for each channel and trial in all directions, we devise various methods to predict the direction of movement from a single trial multichannel data We

use several classification schemes such as Mahalanobis distance, Bhattacharya distance and Gaussian quadratic norm and obtain successful predictions significantly above the random chance level

Obtaining causality relations among signals is important in identifying functional relations between different regions of the brain However, the real world multichannel time series data generated by experiments in neuroscience are inevitably corrupted by noise (both measurement noise and 'noise' due to irrelevant background processes) The third part of the thesis deals with the effect of measurement noise on causality as quantified by Granger causality spectra Granger causality can be defined for a pair of LFP recordings by modeling them as stochastic processes One stochastic process is said to have a causal influence on the other if the residual error in the autoregressive model of the second process (at a given point of time) is reduced by incorporating measurements from the first

First we analytically studied the effect of added noise on Granger causality in bivariate autoregressive processes We are able to derive how this effect depends on the system parameters for AR(1) and AR(2) processes We are able to demonstrate that added noise can give rise to spurious causality and also suppress true causality We confirm these findings through numerical simulations We then provide a practical solution to this problem by implementing a denoising algorithm based on the Kalman smoother and the Expectation Maximization algorithm We show that the correct causal relations are restored when the denoised data is used

We finally apply the above analysis to LFP recordings from distributed neuronal assemblies in somatosensory and motor cortices of macaque monkeys as they maintained steady motor output while pressing a hand lever in a visual discrimination task We are able to resolve discrepancies observed in earlier studies by using the above algorithm